Design of compact dual-mode dual-band SIW filter with independent tuning capability

Naeem, U., Khan, M. B., & Shafique, M. F. (2018). Design of compact dual-mode dual-band SIW filter with independent tuning capability. *Microwave and Optical Technology Letters*, *60*(1), 178-182. https://doi.org/10.1002/mop.30934

Published in:
Microwave and Optical Technology Letters

Document Version:
Peer reviewed version

Design of Compact Dual-Mode Dual-Band SIW Filter with Independent Tuning Capability

U. Naeem[1], M. B. Khan[2] and M. F. Shafique[2]
[1]ECIT Institute, Queen's University of Belfast, NI Science Park, Queen's Road, Queen's Island, Belfast, UK, BT39DT
[2]Center for Advanced Studies in Telecommunication
COMSATS Institute of Information Technology, Tarlai Kalan, Islamabad, 45550, Pakistan

Abstract

This work reports on a novel design of a compact and tunable filter in substrate integrated waveguide technology. The proposed dual band filter is based on resonators that exploit two resonating modes excited in a single SIW cavity. The structure is designed in such a way that the two bands of dual-band filter each having two poles can be tuned independently. This property of the proposed filter makes it a suitable choice for multi-standard applications with fine tuning as envisaged for future generation wireless technologies. The measured results of the fabricated prototypes validate the proposed design concept.

I. Introduction:

Enormous growth in telecommunication services and products has been observed in recent years. Frequency spectrum remains an expensive resource which has to be shared by all of the next generation wireless technologies. Hence there is a great demand for multi-standard and reconfigurable devices and systems. In order for a device to operate at multiple standards the passive components like antennas, couplers, filters can be made tunable. Filter being the most critical part of the RF front-end occupies most of the space and incorporating tuning capabilities

This is the peer reviewed version of the following article: Naeem U, Khan MB, Shafique MF. Design of compact dual-mode dual-band SIW filter with independent tuning capability. Microw Opt Technol Lett. 2017;60:178–182., which has been published in final form at https://doi.org/10.1002/mop.30934. This article may be used for non-commercial purposes in accordance with Wiley Terms and Conditions for Self-Archiving

makes the device even more bulky. It is preferred that the filter used in high frequency circuits is capable of operating at multiple frequency bands and at the same time be as compact as possible. A number of tunable filters have been proposed in recent years which are based on microstrip or coplanar waveguide topology [1 – 4] however, the lower quality factor of these topologies restrict the performance of these filters in stringent requirements. Waveguides on the other hand are popular in higher power handling and much higher quality factor as compared to microstrip or coplanar topologies; also they are preferable at higher frequencies in millimetre and sub-millimetre wave regions because of lesser dispersion. The filters made in waveguides are known for their higher quality factors and higher frequency operations [5 – 6] at the cost of larger physical profile. The trade-off thus developed between the performance and compactness of a filter. Substrate Integrated Waveguides (SIW) are kind of dielectric filled waveguides which have same principal of working as that of air filled waveguides thus they are capable of offering better performance compared to microstrip or coplanar topologies. The performance of SIW technology is however limited by the lossy nature of substrate used. Similar to waveguide based filters, dual or multiple frequency bands can be achieved by utilizing multiple resonant modes [7].

Single and dual-band filters, based on narrow band filter design, have been proposed using degenerated modes in recent years [8]. Degenerated modes are mostly employed to achieve quasi-elliptic filtering functions [9]. In order to achieve dual frequency pass bands that are widely separated from each other, different types of resonators for each pass band can be employed [10] however, for these types of resonators one has to trade-off for the unloaded quality factor of the individual resonators. For planar technologies one option is to choose multiple modes [11]. The major challenge in this case is to dimension the structure optimally for each of the pass bands, independently or quasi-independently. Miniaturization of SIW devices can be achieved by folding the cavity or by using fraction of a mode [12]. The SIW components can also be made compact by loading them with slotted structures [13]. The design of a compact dual-mode dual-band SIW cavity with loaded structure is therefore a tedious task, and one has to encounter many challenges especially when tunability is desired.

In the presented work a dual-mode resonator loaded by slots has been proposed. A dual-band filter has been designed based on the proposed resonators and the tuning capability of the proposed filter has been demonstrated for each of the two bands independently. In section II a detailed description of the proposed dual-band resonator is presented. The following section III employs the proposed resonator into a dual-band filter which has two poles in each of the pass bands. The tuning circuitry and procedure is elaborated in the section IV and it is established that both of the bands can be electronically tuned independently. The proposed work is concluded in the section V.

II. Dual Band Resonator Design

The compact dual band SIW resonator is shown in Figure 1(a). The SIW has been realized by using continuous metalized channels instead of via holes. The proposed resonator is loaded by symmetrical slots, these slots not only reduce the physical dimensions of the resonator but also assist in placing the tuning varactors in the later stage. The proposed resonator structure operates in two modes; the TE_{101} mode and the TE_{102} mode as illustrated in Figure 1(b) and Figure 1(c). It can be observed from Figure 2 that the external quality factor is greatly affected by variation in the inset feed dimensions q and g, the external quality factors for both the modes decrease with the increase in these two parameters. It can be observed that the quality factor for the first mode is more sensitive to the variation in *g*.

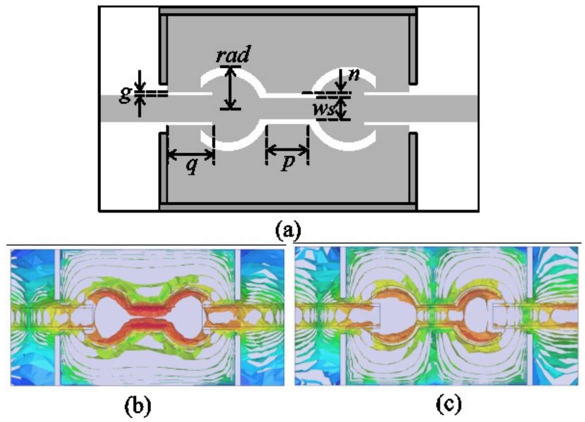

Figure 1 *Proposed dual-mode resonator. (a) Physical geometry (b) E field plot of TE101 mode (c) E field plot of TE102 mode.*

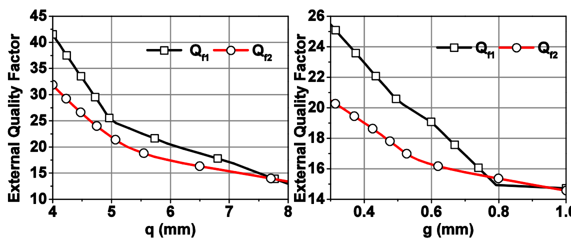

Figure 2 *External Quality factor for the first two modes of the proposed resonator*

The mode charts of the proposed resonator are plotted in Figure 3 for the variables defined in Figure 1(a). It can be deduced from Figure 3(a) - (d) that the first two modes can be selected quasi-independently. The radius *rad* of the loaded slot affects the second mode by keeping the first mode intact however the variable *n* and *ws* can be used to tune the first mode. The variable *p* is helpful in moving both pass bands simultaneously.

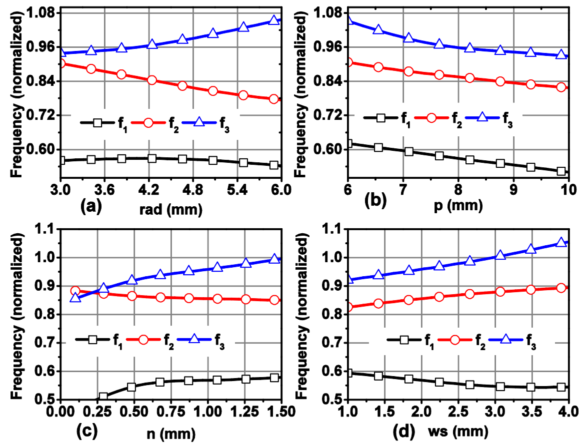

Figure 3 *Mode charts for the proposed resonator (frequencies normalized at 7 GHz).*

III. Design of Dual-Band Filter

A dual band filter with two poles for each band is designed based on the proposed dual mode resonators as shown in Figure 4. The proposed filter is realized on Rogers 4003 substrate with ε_r of 3.55 and tanδ of 0.0027. The thickness of the substrate is 1.524 mm.

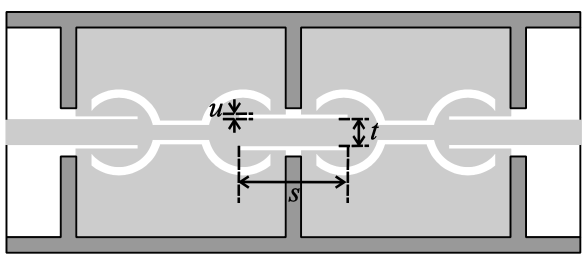

Figure 4. *Proposed dual band filter with two poles for each band*

The coupling coefficients, as given by equation (1), are analysed for both the bands. The coupling behaviour for the two bands as a function of dimensions *s*, *u* and *t*, is shown in Figure 5.

$$K_{12} = \frac{{f_2}^2 - {f_1}^2}{{f_2}^2 + {f_1}^2} \tag{1}$$

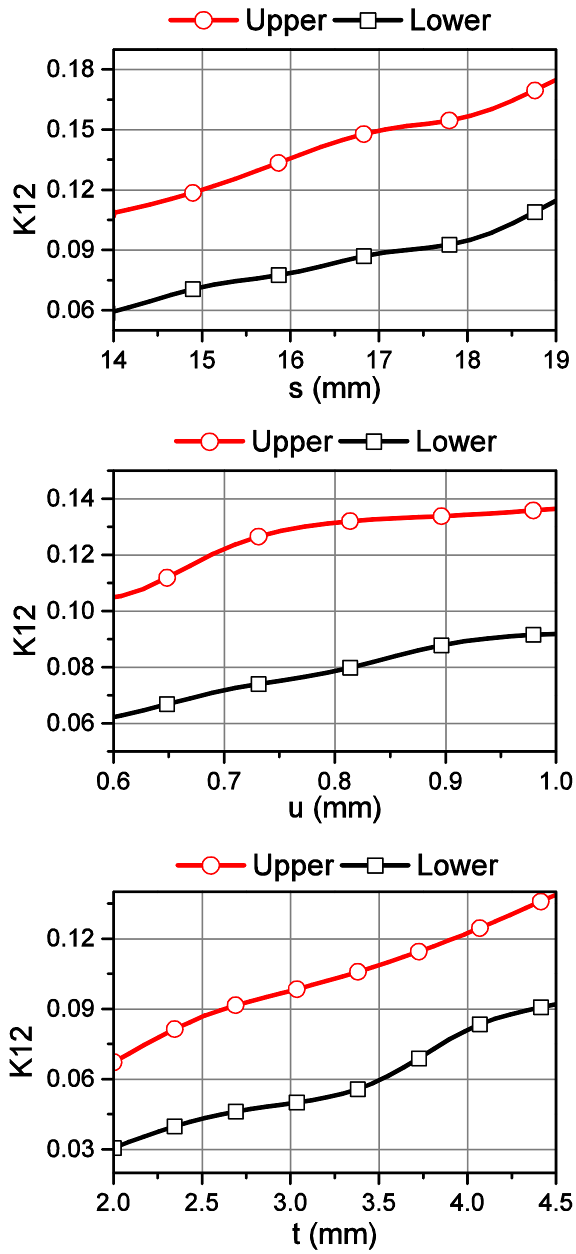

Figure 5 *Dependence of coupling coefficients on variables s, u and t*

The ideal coupling matrices for the upper and lower frequency bands are given in Figure 6.

$$\begin{array}{c} \\ \mathbf{S} \\ \mathbf{1} \\ \mathbf{2} \\ \mathbf{L} \end{array} \begin{array}{c} \begin{array}{cccc} \mathbf{S} & \mathbf{1} & \mathbf{2} & \mathbf{L} \end{array} \\ \left[\begin{array}{cccc} 0 & 1.25 & 0 & 0 \\ 1.25 & 0 & 1.65 & 0 \\ 0 & 1.65 & 0 & 1.25 \\ 0 & 0 & 1.25 & 0 \end{array}\right] \end{array} \quad \begin{array}{c} \\ \mathbf{S} \\ \mathbf{1} \\ \mathbf{2} \\ \mathbf{L} \end{array} \begin{array}{c} \begin{array}{cccc} \mathbf{S} & \mathbf{1} & \mathbf{2} & \mathbf{L} \end{array} \\ \left[\begin{array}{cccc} 0 & 1.31 & 0 & 0 \\ 1.31 & 0 & 1.79 & 0 \\ 0 & 1.79 & 0 & 1.31 \\ 0 & 0 & 1.31 & 0 \end{array}\right] \end{array}$$

$f_0 = 3.4$ GHz $\quad \Delta f = 230$ MHz $\qquad f_0 = 5.18$ GHz $\quad \Delta f = 360$ MHz

Figure 6 *Ideal coupling matrix for both frequency bands*

The simulated and measured results of dual-band dual-mode filter are presented in Figure 7. The two frequency bands are centered at 3.4 GHz and 5.18 GHz with fractional bandwidth of 6.7% and 6.9% respectively. The insertion loss for the lower band is 0.52 dB (simulated) vs 0.82 dB (measured) and for the upper band is 0.45 dB (simulated) vs 1.27 dB (measured). There is a slight shift of lower frequency band due to fabrication imperfection at the inner edges of circular slots due to milling tools' limitations.

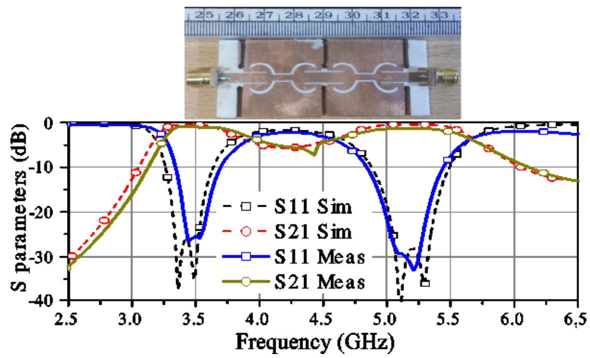

Figure 7 *Measured and simulated responses of the proposed dual-mode and dual-band filter*

IV. Filter Tuning Capabilities

The proposed structure has capabilities to easily incorporate tuning mechanism to vary the two pass-bands independently as shown in Figure 8. The node L is responsible for the tuning of lower frequency band while the node U is responsible for the tuning of upper frequency band. Voltage V_L is applied at node L, and V_U at node U, through a Radio Frequency Choke (RFC). As it was demonstrated in the previous section that the proposed structure allows the independent control of the two resonant frequencies one can therefore place varactors to tune in to the desired band without affecting the other. In each resonator two varactors are installed where one varactor is responsible for the tuning of lower frequency band only and the other one for upper frequency band only. For tuning the lower frequency band a varactor (BB833 of Infineon Technologies) is placed across the slotted gap whereas for tuning the upper frequency band another varactor (same) is placed between node U and a grounded via.

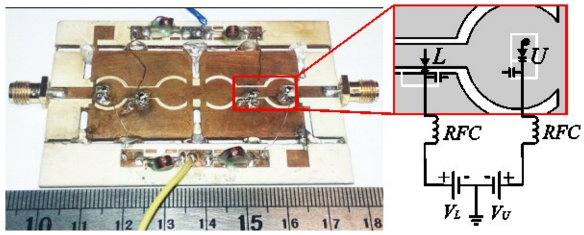

Figure 8 *The fabricated tunable filter. The tuning mechanism is elaborated at right.*

In order to test the tunability, V_U is fixed at 20V and V_L is varied from 8V to 25V. It can be observed from Figure 9 that the lower frequency band can be tuned independently with very small deterioration in the response of higher frequency band.

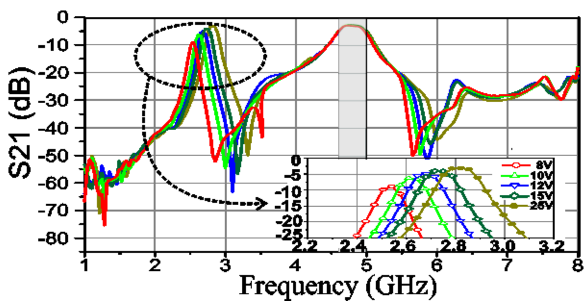

Figure 9 *Tuning of lower band when the upper band is fixed by V_U=20V.*

Figure 10 shows the tuning of higher frequency band when the lower frequency band is fixed by V_L=20V. It can also be observed that the external quality factor changes significantly with the tuning and for the lower tuning voltages (higher capacitance values) insertion loss tends to increase. This limitation can be easy addressed by using lower capacitance range varactor which was verified through simulations, the available varactor used in this study does not give capcitances below 0.7pF. It can also be observed from Figure 9 and Figure 10 that the spurious frequencies are below 20 dB up to 8 GHz also the isolation is better in between the bands in tuned circuits as compared to the fixed filter (Figure 7). The reason for improved isolation is modification in the structure and addition of L and C loading.

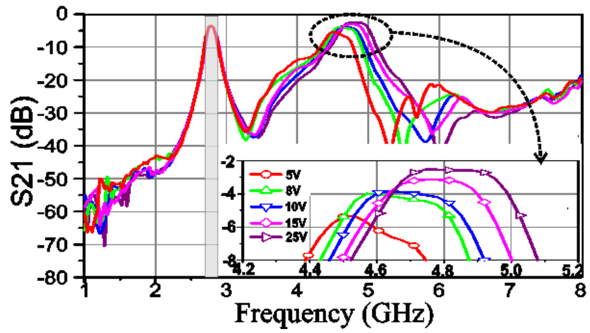

Figure 10 *Tuning of upper band when the lower band is fixed by V_L=20V*

V. Conclusion

A novel design of dual-mode dual-band filter is proposed. The simulated and measured results verify the performance of proposed dual-band filter structure. The independent tuning capability for both passbands is also reported by realizing another prototype that is connected to biasing circuitry and varactors. It is successfully demonstrated that while tuning one frequency band the other retains its original form. The proposed filter can easily be employed in multi-standard applications for future generation wireless technologies where selectable bands are desired with high accuracy.

References

[1]. S. Zhang, Z. Chen, and Q. Chu, Compact tunable balanced bandpass filter with novel multi-mode resonator, IEEE Microwave and Wireless components letters, 27 (2017), 43 – 45.

[2]. H. Tsai, T. Huang and R. Wu , Varactor-tuned compact dual-mode tunable filter with constant passband characteristics, IEEE Trans. on Components Packaging and Manufacturing Technology, 6 (2016), 1399 – 140.

[3]. H. Zhu and A. M. Abbosh, Tunable balanced bandpass filter with wide tuning range of center frequency and bandwidth using compact coupled-line resonator, IEEE Microwave and Wireless Components Letters, 26 (2016), 7 – 9.

[4]. A. Velez, F. Aznar, M. D. Sindreu, J. Bonache and F. Martın, Tunable coplanar waveguide band-stop and band-pass filters based on open split ring resonators and open complementary split ring resonators, IET Microwave Antenna and Propagation, 5 (2011), 277 – 281.

[5]. X. Shang, M. Lancaster and Y. L. Dong, W-band waveguide filter based on large TM120 resonators to ease CNC milling, IET Electronics Letters, 53 (2017) 488 – 490.

[6]. A. Anand and X. Liu, Air cavities integrated with surface mount tuning components for tunable evanescent-mode resonators, Proc. of International Microwave Symposium, 2016.

[7]. S. W. Wong, S. F. Feng and L. Zhu, Multi-mode wideband bandpass filters using waveguide cavities, Proc. of Asia Pacific Microwave Conference, 2015.

[8]. P. Lenoir, S. Bila, F. Seyfert, D. Baillargeat and S. Verdeyme, Synthesis and design of asymmetrical dual-band bandpass filters based on equivalent network simplification, IEEE Trans on Microwave Theory and Tech, 54 (2006), 3090 – 3097.

[9]. U. Naeem and S. Bila, Compact SIW based multimode filters for future generation wireless front-ends, Proc. of European Microwave Conference, 2015, 967 – 970.

[10]. U. Naeem, S. Bila, M. Thévenot, T. Monédière and S. Verdeyme, A dual-band bandpass filter with widely separated pass-bands, IEEE Trans. on Microwave Theory and Tech., 62 (2014), 450 – 456.

[11]. L. Riaz, U. Naeem and M. F. Shafique, Miniaturization of SIW cavity filters through stub loading, IEEE Microwave and Wireless Component Letters, 26 (2016), 981 – 983.

[12]. H. Y. Chien, T. M. Shen, T. Y. Huang, W. H. T Wang and R. B. Wu, Miniaturized bandpass filters with double-folded substrate integrated waveguide resonators in LTCC, IEEE Trans on Microwave Theory and Tech, 57 (2009), 1774 – 1782.

[13]. S. Xu, K. Ma, F. Meng and K. S. Yeo, Novel defected ground structure and two-side loading scheme for miniaturized dual-band SIW bandpass filter designs, IEEE Microwave and Wireless Components Letters, 25 (2015) 217 – 219.